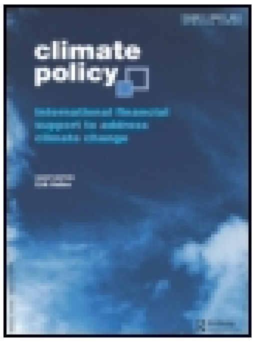

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The role of money and the financial sector in energy-economy models used for assessing climate and energy policy

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ABSTRACT

This article outlines a critical gap in the assessment methodology used to estimate the macroeconomic costs and benefits of climate and energy policy, which could lead to misleading information being used for policy-making. We show that the Computable General Equilibrium (CGE) models that are typically used for assessing climate policy use assumptions about the financial system that sit at odds with the observed reality. These assumptions lead to 'crowding out' of capital and, because of the way the models are constructed, negative economic impacts (in terms of gross domestic product (GDP) and welfare) from climate policy in virtually all cases.

In contrast, macro-econometric models, which follow non-equilibrium economic theory and adopt a more empirical approach, apply a treatment of the financial system that is more consistent with reality. Although these models also have major limitations, they show that green investment need not crowd out investment in other parts of the economy – and may therefore offer an economic stimulus. Our conclusion is that improvements in both modelling approaches should be sought with some urgency – both to provide a better assessment of potential climate and energy policy and to improve understanding of the dynamics of the global financial system more generally.

POLICY RELEVANCE

This article discusses the treatment of the financial system in the macroeconomic models that are used in assessments of climate and energy policy. It shows major limitations in approach that could result in misleading information being provided to policy-makers.

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Carbon finance; economic models; energy models; financial mechanisms; macroeconomic effects

1. Introduction

1.1. The world can meet the 2°C target – but who will pay?

There is a gradually emerging consensus that a global emissions pathway that is consistent with the target of keeping emissions concentrations below 450ppm, and thus of having a 50% chance of limiting anthropogenic climate change to 2°C above pre-industrial levels, is technologically feasible (IPCC, 2014). The question of whether the 2°C target will be met or not is therefore a political one to do with the allocation of scarce resources; essentially to determine who will pay if the world is to meet its collective target.

It seems beyond doubt that targets for emissions levels will not be met without the introduction of new policy. As outlined in Grubb, Neuhoff, and Hourcade (2014), there are three main forms this policy could take:

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- Policies to improve the use of energy with existing technologies, such as enforcing efficiency standards through regulation.
- Policies to ensure an efficient allocation of resources given existing technologies, for the main part through market-based mechanisms (market-pull policies).
- Incentives to develop new technologies, for example through providing tax credits on R&D expenditure (technology-push policies).

These policies differ substantially in scope, and their responsibility may not even fall under the same government departments, but they do have some common characteristics. While all of them will involve a reallocation of economic resources compared to what would have happened without government intervention, most will also involve substantial amounts of investment. The effects of the policies will therefore be felt both in the real economy and across the financial system; understanding the interaction of investors in low-carbon technologies with the banks and other financial institutions that provide the necessary credit and the companies that produce or install the equipment will be key to assessing overall impacts.

In summary, all of these types of policy will lead to economic winners and losers, with financial consequences at both the micro and macro levels. In a modern economy, all must therefore be justified prior to implementation. Quantitative models contribute to this process by providing evidence of the likely costs and benefits of potential policy.

1.2. The role of E3 models and IAMs in policy analysis

The emphasis placed on computer modelling in climate and energy policy has been increasing steadily as data have improved and additional computer power has allowed the development of more complex tools. Large-scale climate models and Integrated Assessment Models (IAMs) are central to the analysis carried out by the Intergovernmental Panel on Climate Change (IPCC) both to estimate the current emissions trajectory and paths with which there is a reasonable chance of staying within the 2°C target.

When it comes to assessing the implications of climate and energy policy on the wider society, E3[1] (Energy-Environment-Economy) models are applied to estimate impacts on indicators such as gross domestic product (GDP), welfare and employment. The terminology is not always used consistently, but in this article E3 models are defined as essentially macroeconomic models that have been extended to include some physical relationships. Their use has been well-established since at least the IPCC's second assessment report (IPCC, 1995) and the relative weight placed on model results has increased over the past decade. For example, the European Commission's *Better Regulation* Guidelines (European Commission, 2015, p. 32) state that for any policy assessment:

> Where possible, sensitivity and/or scenario analysis should be conducted to help test robustness of the analysis.

with a footnote added to the text that takes the reader directly to a description of the main quantitative methods that can be applied.

The Better Regulation guidelines note that not all impacts can be quantified but require that all quantitative evidence is assessed. The EU's previous *Impact Assessment* guidelines were even clearer:

> If quantification/monetisation is not feasible, explain why. European Commission (2009, p. 39).

Taken together, and given the often-disparate effects of climate policy on the economy, the message is quite clear – for any new climate or energy policy proposals to be accepted at European level it is necessary to provide model-based evidence of the macroeconomic impacts.

1.3. Different types of macroeconomic models

In many cases policy makers' understanding of macroeconomic models has not kept pace with the more prominent role that the models play in policy analysis. This is unfortunate as it is not possible to interpret properly the results from the models without understanding the underlying mechanisms; and, furthermore, there are substantial differences between the ways the models work. It is recognized in the field that there is an inherent difficulty in communicating an understanding of complex tools to time-pressured policy makers who may not come from a quantitative or economic background. There are efforts to address this, for example in providing specialized training.

The models that are used to assess the macroeconomic impacts of climate and energy policy fall broadly into two groups. These are[2]:

- Computable General Equilibrium (CGE) models that are usually described as being based on neoclassical microeconomic assumptions. These models assume that agents (e.g. firms, households) optimise their behaviour so as to maximise their personal gains. Well-known international CGE models include GEM-E3 (Capros, Van Regemorter, Paroussos, & Karkatsoulis, 2013), GTAP (Hertel, 1999), and the Monash model (Dixon & Rimmer, 2002). The *Handbook of Computable General Equilibrium Modeling* (Dixon & Jorgensen, 2012) describes in detail how these models work. Model intercomparison exercises, such as those carried out by the Energy Modelling Forum (e.g. Weyant & de la Chesnaye, 2006) typically compare the results from different CGE models.
- Macro-econometric models that are derived from a post-Keynesian economic background.[3] These models do not assume that agents optimize their behaviour, but instead derive behavioural parameters from historical relationships using econometric equations (which allow for 'bounded rationality'). Well-known international macro-econometric models include E3ME (Cambridge Econometrics, 2014) and GINFORS (Lutz, Meyer, & Wolter, 2010; Meyer & Lutz, 2007).

The aim of this article is not to describe in detail the differences between the modelling approaches.[4] The focus of this article is instead on describing how the different models represent the global investment that will be required to meet the 2°C target, how such representations influence model results, and how this information can be interpreted by decision makers. Closely tied to this issue is the question of how the models treat banks, money and the financial sector, which is introduced below.

1.4. Why is the treatment of money and finance important in macroeconomic models?

It is beyond doubt that substantial investment will be required to meet the 2°C target. The IEA (2014, p. 93) estimates that at global level \$2.4trn (2013 prices) 'clean energy investment' must be made annually in its 450ppm scenario. All of this investment must be financed somehow; although some could be diverted from investment in developing fossil fuel resources, the investment-intensive nature of low-carbon technologies (e.g. renewables, nuclear, energy efficiency) means that any policy scenario in which emissions are reduced is likely to require an increase in energy-sector investment. The question of how the investment is financed, and whether more investment resources can be mobilized, is therefore key to understanding the economics of a low-carbon transition.

There are, however, also other reasons to focus attention on finance. As was made painfully aware by the financial crisis and subsequent recession, even sophisticated macroeconomic models have only a rudimentary treatment of finance.[5] While there have been attempts outside mainstream economics to build macroeconomic models with better links to finance (originating from Minsky, 1982), these are not developed enough to apply to climate or energy policy.[6] The treatment of banks and the financial sector is therefore done largely by assumption. Furthermore, as is demonstrated below, these assumptions vary enormously between the different modelling approaches. The goal of this article is to review the state of the art in theory and modelling, and make the reader aware of how the choice of model type influences the outcomes of policy assessments, and for what specific reasons.

The main modelling approaches are described in Section 3. First, however, we describe the underlying theory and how it relates to the different schools of economic thought. In Section 4 we turn attention to the lessons for policy makers from our analysis. Section 5 concludes.

2. Money and the financial sector in the different schools of economic thought

2.1. Introduction

The focus of this article is on the impacts of assumptions in macroeconomic modelling approaches, and thus it is necessary to have a basic understanding of the underlying theory and philosophy in order to understand how the models work. This section therefore gives a brief overview of how finance is treated in the most relevant schools of economic thought.

2.2. Money and finance in neoclassical and new Keynesian economics

All trained economists are familiar with the Efficient Markets Hypothesis (EMH) that forms the core of financial theory in neoclassical economics. The EMH postulates that markets are 'efficient' and that the prices that are set accurately reflect all of the available information. The underlying assumptions, such as the same information being available to all individuals who act rationally, are broadly, if not entirely, consistent with those used in CGE models. Although the EMH has been criticized heavily for making these assumptions, especially since the global financial crisis, it is still the standard approach that is taught in economics textbooks.

While the EMH is certainly relevant to the modelling of energy and climate policy, for example in the way that optimal carbon prices are determined in most modelling approaches, neoclassical theory of the money supply is much more important in determining the macro-level impacts of climate policy in CGE models (e.g. GDP, welfare), as is shown in the next section. In neoclassical theory, the money supply is effectively determined by the central bank which, in modelling terms, makes it exogenous. If there is an increased demand for money from commercial banks, government or private sector institutions, interest rates (i.e. the price of money) will adjust in response and there will be no change in the overall supply of money.

Furthermore, if the central bank does increase the money supply (in nominal terms) this does not have any impacts on real rates of economic activity. Instead, prices and inflation rates automatically adjust by the same relative amount, an approach that is consistent with the optimization principles applied in the modelling; if all available resources are being used optimally already then making more money available will just lead to higher prices for these resources. Within economics this theory is referred to as the *neutrality of money*.

The New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models add a short-run component to the CGE approach but, in terms of money, typically hold the same properties. As climate policy analysis typically focuses on long-run outcomes, and DSGE models are not commonly used for assessing climate or energy policy, this is not developed further in the present article.

2.3. Money and finance in post-Keynesian economics

Money plays a central role in post-Keynesian economics – as noted in King (2015, p. 18), the term appears in the full title of Keynes' *General Theory*; in the recent textbook by Lavoie (2015) money and finance are introduced *before* the real economy. The various characteristics of money are described in detail in Barker (1996, Ch3, 2010). In contrast to the neoclassical approach, post-Keynesian economists follow a theory of 'endogenous money',[7] that has deep roots in economic uncertainty (Fontana, 2009, Ch5 onwards; King, 2015, p. 228). The approach is based on the fact that in a modern economy, most of the money is created by commercial banks through the advancement of new loans. Because of leverage effects, banks do not need to receive additional deposits to make new loans.[8]

When the banks do make new loans, they create simultaneously a matching deposit in the borrower's bank account, thereby creating new money. McLeay, Radia, and Thomas (2014) provides a very clear summary of the processes involved but, in summary, the volume of loans and therefore money supply is at least in part determined by broader macroeconomic conditions (i.e. whether the banks see profitable commercial opportunities for a given level of risk, in turn depending on levels of confidence). Commercial banks make the loans; depending on whether reserve requirements exist, and their magnitude, central banks are assumed to print 'on demand' the amount of money required by the commercial banks in order to underwrite these loans.[9] In advanced economies this is what the central banks generally do.

In post-Keynesian economics, the money supply is also important because it leads to real economic effects, particularly in the short run but potentially with long-run impacts. As prices do not adjust instantly (or even at all), providing more money to make purchases can lead to an increase in aggregate demand, pulling previously unused resources into the system. This is how 'fiscal stabilizers' can provide support to an economy during a recession. Some post-Keynesian economists also suggest that this is how lower interest rates would affect the real economy (by encouraging banks to make loans that would stimulate aggregate demand) and quantitative easing would follow a similar idea. However, in both cases the banks must be willing to make the loans if demand is stimulated, which is more likely to be based on expectations of future profits. While the New Keynesian theory also favours active interest rate policy, post-Keynesian economists stress features such as uncertainty and path dependence, i.e. that short-term developments can influence long-term outcomes.

The post-Keynesian economists are themselves divided into two groups: horizontalists and structuralists (Pollin, 1991). The names reflect the shape of the money supply curve (in neoclassical theory it is vertical, i.e. fixed). If the money supply curve is horizontal, banks are free to lend infinitely without restriction; the sole limit on lending is thus the degree of profitable opportunity (Moore, 1988). Interest rates are exogenous under this approach, although some variants with upward sloping curves have been suggested. Structuralists endogenize the interest rate by adding further real-world factors, but at the expense of a more complex theory (Palley, 2013).

Of crucial importance is that the empirical evidence supports the post-Keynesian formulation. Anger and Barker (2015, p. 183) list numerous studies that show the limited role of the central bank in controlling the amount of credit available, and therefore the supply of money to the economy is largely controlled by commercial banks. Arestis and Sawyer (2011, p. 3) conclude that 'the analysis of macroeconomies cannot be reduced to studies of economies without money and finance'. As noted in the introduction above, this finding is particularly relevant to policies that are designed to promote investment, including climate and energy policy.

2.4. Money and finance in the post-Schumpeterian (evolutionary) school

The post-Schumpeterian school complements post-Keynesian thinking. It states that credit creation by financial institutions arises with a purpose: to give entrepreneurs purchasing power for business development. Money creation is thus a key component of the post-Schumpeterian school, also known as evolutionary economics. In Schumpeter (1934, 1939) and subsequent work of the field (Freeman & Louça, 2001; Perez, 2001), productivity growth is effectuated by the entrepreneur. With little funds but ideas, the entrepreneur innovates in the production process by inventing *new combinations of resource use* which increase productivity and/or lower costs. If he is successful, innovation confers him a temporary monopolistic profit, until the time when the competition catches up, at which point economy-wide prices have declined. In the long run, this generates economic development. To carry this out, the entrepreneur applies for finance, at financial institutions, which take decisions based on the credibility of his business plans, past successes, and general confidence in the economy.

This perspective is thus consistent with that of post-Keynesians: in fact, it is a micro economic counterpart of the same theory. This is important for several reasons: (1) finance is almost always awarded to entrepreneurs for productivity enhancing and/or expansion activities *before* they are carried out, and play the role of an enabling factor, (2) finance is allocated on case-by-case basis, solely determined by the credit-worthiness of the entrepreneur and his business case, and the existing balance sheet of the bank, (3) aggregate finance depends on the amount of innovative activity taking place and generating apparently profitable opportunities for financial institutions.

Given that finance is provided based on banks' expectations of return and entrepreneur track-record, finance is naturally attracted to firms with established high innovation[10] potential and levels of activity. Therefore, further understanding of finance in a microeconomic perspective requires better representation of the process of innovation itself. In particular, innovative activity is known to cluster, and so does its associated finance (e.g. great historical waves of innovation see Freeman & Louça, 2001; Freeman & Perez, 1988; Perez, 2001).

3. Money and the financial sector in the different modelling approaches

3.1. Introduction

The previous section showed that the treatments of money and finance vary considerably between the different strands of economic theory. In this section, we turn attention to the practical application of these theories through computer models. The explanations focus on the assessment of climate and energy policy but it would be possible to draw the same conclusions for any type of policy that was investment intensive and for which the model user was interested in the long-run outcomes.

It is important to note that all the different models observe the macroeconomic identity that savings should equal investment but, as explained below, they have quite different interpretations of how the balance is met. First, we describe the processes involved in the neoclassical CGE models before explaining the roles of money and finance in the large-scale post-Keynesian macro-econometric models. We then summarize the key differences between the two most commonly applied modelling approaches and provide an example relating to climate policy. Finally, we discuss some of the other conceptual approaches that could be applied in the future.

3.2. The role of money and finance in CGE models

The sixth part of Walras' *Elements of Pure Economics* (Walras, 1954), widely regarded as the bible for CGE modelling,[11] is titled 'Theory of Circulation and Money'. This title hints at the role of money in the economy in CGE models – as a means to allow the transactions of goods and services. Lessons 28 and 29 of the book expand on the approach; the demand and supply of money are described in micro terms, for example with money being held by consumers to allow the immediate purchases of goods and services (p. 316). A similar definition for producers is provided on page 317.

After explaining the reasons for holding cash, Walras describes the role of lending and borrowing money in the economic system, showing a clear one-to-one link from savings to investment:

> That is not all … Capital being defined as 'the sum total of fixed and circulating capital goods hired, not in kind, but in money, by means of credit' … This quantity of repaid capital, to which land-owners, workers and capitalists add a certain excess of consumption over income, or from which they subtract a certain excess of consumption over income, constitutes the day-to-day amount of savings available for lending in the form of money. (Walras, 1954, p. 317, emphasis in original)

Walras also discusses the impact of changes in the money supply (pp. 327–329). The assumption is that the value of money is only determined by the value of the goods and services it may purchase and hence is 'inversely proportional to its quantity' (Walras, 1954, p. 329). Even in the 19th century Walras was aware of the restrictive assumptions relating to price adjustments that were necessary to justify this proposition (p. 328); he describes the treatment as one of 'almost rigorous exactness' but it is consistent with the neoclassical theory outlined in the previous section.

The treatment of money in modern CGE models remains very closely based on the approach described by Walras, with the total money supply fixed in real terms and money used as a means of exchange rather than something that can have an impact on rates of real economic activity. The current handbook (Dixon & Jorgensen, 2012) pays little attention to money. A search for the word 'money' reveals first a description of the MAMS model (Lofgren, Cicowiez, & Diaz-Bonilla, 2012) that includes:

> Like most other CGE models, MAMS is a 'real' model in which inflation does not matter (only relative prices matter). Given this, there is no significant gain from having a separate monetary sector. (Logfren et al., 2012, p. 234)

Then a similar paragraph for the 1-2-3 model (Robinson & Devarajan, 2012):

> It [the exchange rate] can be seen as a signal in commodity markets and is in no sense a financial variable since the CGE model does not contain money, financial instruments or asset markets. (Robinson & Devarajan, 2012, p. 281)

Only the G-Cubed model description (McKibbin & Wilcoxen, 2012) talks about money at length, although it must be noted that it is in the context of non-equilibrium (i.e. it is not pure CGE). The other search results (excluding DSGE descriptions) refer to money as a metric for presenting model results rather than something that can impact on these results.

Looking further afield, some CGE approaches have been developed to include a financial sector. Most applications are derived from Bourguignon, Branson, and de Melo (1989) and have been applied to assess policies aimed at improving macroeconomic stability. Despite financing being a key issue, applications related to climate and energy policy are extremely limited, with an extended version of the GEM-E3 model (Capros et al., 2013) providing the only real examples (European Commission, 2015). Although it should be noted that there are still restrictive assumptions involved, this does at least point the way for a possible future improvement to CGE models and some of the advances on the basic approach so far have been impressive.

3.3. The role of money and finance in post-Keynesian E3 models

There are only two post-Keynesian macro-econometric models that are used for E3 analysis at global level: the E3ME and GINFORS models. The general principles underlying both models with regards to money and finance are the same, although the models differ somewhat in terms of detail. To avoid repetition, this article focuses on the E3ME model, although it is noted that most of the description and the same conclusions could be applied for GINFORS. The GINFORS model is described in more detail in Meyer and Lutz (2007) and Lutz et al. (2010).

E3ME combines input-output analysis with sets of econometric equations that determine the components of aggregate demand and price levels. The basic economic framework is extended to incorporate physical flows of energy use, materials consumption and greenhouse gas emissions. The model's parameters are derived from time-series historical data and it projects forwards annually to 2050.

The role of money and the financial system is not covered directly in the current version of the E3ME model manual (Cambridge Econometrics, 2014) and the treatment of money could be described as largely implicit. Traditionally the model has provided a 'horizontalist' approach (see previous section) to banks, lending, and the money supply but the approach has recently been revised. Investment is determined by expectations of future output levels, which (following Keynes) are based on current activity. The interest rate is set by a Taylor rule (having previously been exogenous) and there are no set limits on the amounts that banks can lend. It should be noted that this does not mean that banks are allowed to lend completely freely as past regulations will be factored into the model's econometric parameters which are derived from historical data. However, overall the implication is that an improvement in economic conditions will lead to an increase in investment and the demand for money which will be followed by an increase in the money supply. This means that there is no assumption that an increase in investment must be financed by an increase in savings or reduction in investment elsewhere.[12] Instead, an increase in investment can be financed by an increase in public and/or private debt – and the savings-investment identity is maintained through an expansion of the economy that generates additional savings. Or, to put it another way, capital markets do not enforce a crowding out of investment.

This feature would possibly not matter if the model embodied other equilibrium properties. For example, if full employment were obtained, there would be no additional workers left who could be employed to build any new equipment or infrastructure. However, the demand-driven nature of the model means that this is not usually the case, and unemployment exists in E3ME. So, an increase in investment levels can lead to an overall increase in economic activity rates. This sets the model apart from the results that are typically obtained by CGE models. Figure 1 describes the process; it is important to note in the figure that there is no arrow from investment demand to the other components of final demand (i.e. consumption), meaning that higher investment levels can in theory lead to higher levels of GDP and employment.

3.4. A post-Schumpeterian view: the entrepreneur borrowing to invest in new technology

Modelling climate change mitigation policy is often done from a 'bottom-up' technology perspective, and this provides an opportunity to study the links between technology, finance and the wider economy. While in E3ME the process of money creation for production growth is implied but not described explicitly, connecting explicit models of technological change, with investment and price feedbacks, allows a more explicit analysis: studying

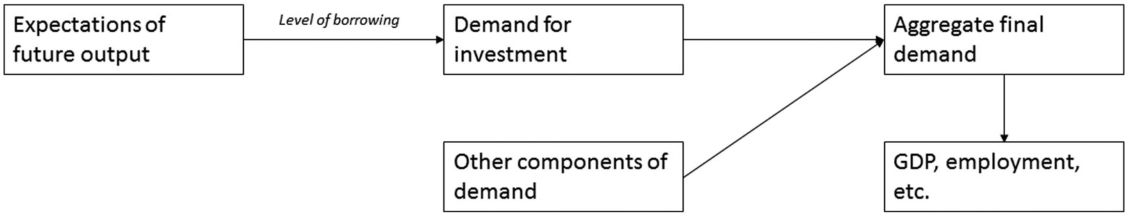

Figure 1. Summary of financial linkages in the E3ME model.

the process of money creation for financing specific technology ventures. It furthermore adds a clear post-Schumpeterian perspective to modelling through a micro-level explicit representation of the entrepreneur seeking finance to invest in technology. In a context of climate change mitigation, this is a crucial aspect to explore (Lee, Pollitt, & Park, 2015; Mercure et al., 2015).

The first tool to do this in detail is the Future Technology Transformations model (FTT, Mercure, 2012; Mercure et al., 2014). FTT replaces the standard social planner in bottom-up modelling with an evolutionary model of technology selection and diffusion in which the individual investor sits at the core. FTT has been linked to E3ME, providing the micro-level representation of the entrepreneur that is otherwise missing from the model. The combined system shows that in scenarios where policies incentivize investors to adopt new technologies, the additional investment, in comparison to a baseline, does not crowd out investment elsewhere: money is created to finance these ventures, although the debts must be repaid over time. FTT combined with E3ME therefore creates a modelling system that contrasts with equilibrium approaches: money is lent by banks for financing evolving technology developments, which are paid back through higher receipts from consumers over the lifetime of the new capital. Therefore, in contrast to equilibrium approaches where macroeconomic costs are incurred first, and benefits may arise later, here, macroeconomic benefits arise first, and costs are incurred later (see European Commission, 2016). However, the banks must be willing to lend to investors in the first place, meaning that they must have confidence that the investments are profitable.

3.5. Summary of features of the models – and a worked example

Table 1 summarizes the key findings of the sections above.

To illustrate these features, one can take the example of a carbon tax with revenue recycling (e.g. through reduced income/corporate taxes). If the policy is revenue neutral overall, then a CGE model is considering a reallocation of resources – a new optimal point in sectoral prices space – which will take us away from the optimal economic starting point and therefore reduce rates of economic activity. But in the macro-econometric framework there is the possibility that the policy stimulates additional investment financed by borrowing, in which increasing debt levels contribute to aggregate demand (as described in Chapter 12 of Keen, 2011), drawing upon unused economic resources to increase overall production levels. Higher current rates of output will lead to expectations of higher future rates of output, and there is a long-run increase in production levels

Table 1. Key characteristics of the models.

	Standard CGE model	E3ME model
Theoretical background	Neoclassical	Post-Keynesian
Money supply	Exogenous	Endogenous
Capital market crowding out	Yes – full	No
Price adjustment	Instant	Dynamic over time
Money neutrality	Yes	No
Capacity constraints	Current production	Implicitly given, based on recent history
Labour crowding out	Yes – full	Partial, increasing towards full employment
Other crowding effects	Yes – full	Only in short term, if growth exceeds trend rates

which will be used to pay down the initial borrowing. This results in higher GDP and (possibly) employment levels (see e.g. Barker, Alexandri, Mercure, Ogawa, & Pollitt, 2015).

Taking this example further into the electricity sector, the first requirement for investment is that there is expected to be a future shortfall in the supply of electricity, which will be made regardless of whether there is a carbon price or not. The interaction with the financial sector relates to how the shortfall is met; all technologies require up-front investment, but some (e.g. nuclear, renewables) more than others. The amount of lending from banks depends on how financially attractive these capital-intensive technologies may be (which is determined in most modelling approaches by comparing 'levelized costs'). The relative attractiveness of the different technologies thus influences the total level of investment made by the sector, with a likely preference for investment-intensive technologies in the case where a carbon tax is levied.

The carbon tax will therefore have important short-term real-economy implications in terms of the production and job creation that result from investment activities, as long as the investment in the electricity sector does not crowd out investment elsewhere. However, once the initial investment has been made, significant levels of debt may remain, which leaves society to live with a legacy of debt servicing payments, of which the costs would be likely given to consumers through higher electricity prices. Depending on whether this transformation has enhanced productivity growth and/or international competitiveness, the transformation may be beneficial or detrimental to economic performance in the long run.[13]

3.6. Alternative modelling approaches that could be applied in the future

While CGE and large-scale macro-econometric models are the approaches most used at present for informing policy-making, it is important to note that there are other methods being developed. These models could potentially be used in policy-making if they were scaled to real-world quantities and data; but few or none have been so far, and thus they remain in the academic sphere.

Stock-Flow Consistent (SFC) modelling has received a lot of attention recently, particularly in the wake of the 2008 financial crisis. Strictly speaking, the models are detailed accounting tools of the financial system but they are typically associated with post-Keynesian economic principles. Essentially, they provide the representation that is missing explicitly from the large-scale macro-econometric models described above. Berg, Hartley, and Richters (2015) provides a good introduction to the approach, and Caverzasi and Godin (2013) place it in a historical context. SFC modelling is not restricted to pure accounting and can include behavioural elements (e.g. Safarzyńska & van den Bergh, 2017).

Many of the SFC models that have been developed are more conceptual in nature, for example lacking the detailed sectoral information that is typically required for policy assessment. However, SFC models have been used to address some high-level questions related to environmental and financial sustainability, such as the compatibility between positive interest rates and the steady-state economy proposed by ecological economists (Berg et al., 2015; Cahen-Fourot & Lavoie, 2016). SFC models have parallels with the way that systems dynamics approaches are used in accounting of physical stocks and flows, and there are linkages between the two approaches (e.g. Dafermos, Nikolaidi, & Galanis, 2016). In summary, SFC modelling is a line of research that should be of interest to both CGE and large-scale macro-econometric modellers.

Another research area that has received a lot of attention over the past decade is agent-based models (ABMs). To many economists, the aggregation of agent behaviour through the representative agent appears unsatisfactory, since it can miss out salient features of many economic problems. ABMs have been candidates to solve the aggregation problem. The strength of ABMs is that they provide a link between micro and macro level behaviours, which in CGE/DSGE models requires accepting the assumption of identical agents, while in post-Keynesian modelling requires the post-Schumpeterian links. Interest in ABMs in economics has grown particularly since Beinhocker (2007) advocated the approach, but one of the best-known examples of ABMs in the field relates to finance and was published much earlier (Arthur, Holland, LeBaron, Palmer, & Tayler, 1997). Meanwhile, Dosi, Fagiolo, and Roventini (2010), Dosi, Fagiolo, Napoletano, and Roventini (2013), and Dosi, Fagiolo, Napoletano, Roventini, and Treibich (2015) were able to reproduce many stylized facts of real and monetary modern economies using an ABM which, however, is not calibrated to actual data, and thus remains exploratory. The downside of using ABMs is that since interactions between agents are not calibrated to data, it is not always clear what one learns from the model outcomes, as the emerging complexity rapidly obscures the nature of phenomena, and strongly depends on the definition of these interactions.[14]

SFC modelling and ABMs may also in future pick up on some of the other limitations of the more widely-used modelling approaches. For example, neither CGE nor macro-econometric models in their current forms are well-equipped to assess the financial and macroeconomic impacts of bankruptcies in large firms, or stranded assets more generally. This situation helps to contribute additional uncertainty around the 'carbon bubble' with a wide range of estimates around potential impacts of investor losses. Alternative approaches (e.g. Battiston, Mandel, Monasterolo, Schütze, & Visentin, 2016) are therefore urgently needed to address these gaps.

4. Implications for policy makers

So far, this article has outlined the following:

- Macroeconomic models are used frequently to estimate the economic costs and benefits across a range of policy areas, including climate policy.
- Much climate and energy policy (e.g. renewables, energy efficiency) requires substantial investment and financing for this investment.
- The treatment of finance varies considerably between modelling approaches and (especially) in the most common CGE approach it is largely constrained by assumption.

There is therefore a difficult task for policy makers to interpret and compare model results, given the differences in treatment of money, the financial system and investment, much of which is relatively undocumented.

The key result in economic terms, however, is that:

> In a CGE model, an increase in investment due to climate policy will always mean either a reduction in investment elsewhere in the economy or an increase in savings at the expense of current consumption, due to financial crowding out effects. Due to diminishing marginal returns, this reallocation of investment is effectively certain to have a negative effect on total economic production levels.[15]

> In contrast, in a non-equilibrium macro-econometric model, if investment opportunities are sufficiently commercially attractive, banks may choose to increase their lending, leading to an increase in net credit and the broad money supply, in turn stimulating real economic activity and leading to higher rates of output and employment. While in the longer term there may be costs as loans are repaid, higher rates of production can stimulate further activity, meaning long-term impacts need not be negative.

To put it another way, in terms of contribution from the financial sector, a CGE modelling approach represents a worst-case outcome for policy makers; the starting point is one of optimal use of resources (including in the financial sector) from an economic perspective and the policy shows the negative impacts of intervention and a reallocation of limited resources. This raises the question of how close the world is to an optimal starting point? In 2016 the answer seems to be 'not very' with a combination of economic recession, demographic change and a shift to less capital-intensive industries leading to a persistent 'global savings glut' (Zenghelis, 2011). The continuation of Quantitative Easing (QE) in Europe, a policy designed to increase the money supply directly without the intermediation of banks, suggests a position that is far from optimized. However, while all of this suggests benefits from encouraging investment in the short term, climate policy scenarios usually consider the period out to 2030 and beyond; a wide range of possible outcomes can be predicted for macroeconomic conditions so far ahead.

The simulation-based approach offered by the non-equilibrium macro-econometric model is much more in line with how the financial system works in most countries but is by no means perfect. It does not present a best-case outcome but, by assuming that finance will generally be available for mitigation options, it is more likely to be erring on the optimistic side. Indeed, the power of decision for the creation of loans belongs to banks, and banks can at any point refuse to lend if they do not see profitable investment opportunities. It would, therefore, be desirable to test the sensitivity of model results to the addition of constraints (e.g. by adjusting interest rates, or changing baseline unemployment rates) to see how important the assumptions are – a similar exercise could be carried out with a CGE model but the model would become difficult to solve in non-equilibrium conditions.

One possible solution to the problem is to use both modelling approaches to test climate or energy policy, as is now common within the European Commission (e.g. European Commission, 2015). Although this clearly requires additional resources for policy analysis, there are benefits both in terms of obtaining a range of results but also in the discussion between the model results, which can help policy makers to understand some of the key assumptions that are involved (including the treatment of money and finance).

5. Conclusions

If the world is to meet the 2°C target, it is clear that substantial levels of additional investment will be required. How this investment is financed is a key question for policy makers, as has become clear from the United Nations Framework Convention on Climate Change (UNFCCC) negotiations in recent years.

In attempting to assess the costs and benefits of climate policy (and also other policy areas), policy makers now frequently turn to macroeconomic models to provide estimates. However, as shown in this article, the majority of these models make the assumption that the investment can only be financed by taking investment from elsewhere in the economy, or by reducing current consumption (and welfare) levels. This is not consistent with how the financial system works in the real world, as demonstrated by the real-world use of interest rate policy and QE, which would have no impact in these models.

The alternative approach, offered by the relatively few models that follow post-Keynesian principles, is not without limitations either but offers a version of the financial system that is closer to that which one can observe. However, questions of economic capacity which have only a limited representation in the model place a burden on the model operator to ensure that policy scenarios are realistic.

In summary, policy makers must be aware that there are important distinctions between the two main modelling approaches that they use for their policy analyses. Both modelling approaches could and should be improved further to include a clear and explicit representation of the financial system. On the surface, it looks like the post-Keynesian modelling approach is also in a better position to adapt, as assumptions about optimization and fixed supply are fundamental to the CGE approach, which lends CGE models significantly less flexibility (although it is noted that some efforts have been made to incorporate a financial sector in these models). At the same time, there is clear merit in further developing SFC models and even agent-based models so that they could contribute to formal policy analysis. For example, neither macro-econometric models nor CGE models can assess the likelihood or effects of debt defaults, but this is an important possible outcome when agents are allowed to take on debt.

Whichever method is chosen, when assessing policy, decision makers and policy analysts must identify what the implications are of their choice of models and associated underlying assumptions. If a single modelling approach is applied, at present the post-Keynesian approach looks more appropriate, at least in relation to finance. Alternatively, the simultaneous use of models with different theoretical underpinnings could allow for safer identification of possible ranges of economic outcomes.

Given how important issues of finance are in estimating the impacts of climate and energy policy in the models, our view is that improving the treatment of finance in the models should be given priority in coming years. The benefits would be a more accurate representation of the impacts of climate policy and investment across the world's economies more generally.

Notes

1. This means models where all the main macroeconomic national accounting variables are endogenous outputs from the model so, for example, pure energy systems models are generally excluded.
2. There are also some models that fall between these two definitions, although their treatment of finance will generally follow the neoclassical approach. Small-scale Integrated Assessment Models (IAMs) such as DICE also fall into this category. Large-scale IAMs that cover the economy endogenously typically incorporate a CGE model. Other possible approaches include systems dynamics models (in relation to this article similar in structure to macro-econometric models), Stock-Flow Consistent (SFC) models and agent-based approaches. SFC and agent-based models are described briefly in Section 3.

3. Again, there is a potential issue with terminology here. We denote macro-econometric models as large-scale tools that are derived from a post-Keynesian economic background. This category does not include CGE models that have parameters which have been estimated using econometric techniques.
4. Pollitt, Lee, and Park (2015), Knopf et al. (2013) and Scrieciu, Rezai, and Mechler (2013) expand on this in the context of climate policy; European Commission (2013) provides a practical example in relation to EU policy to meet the 2°C target.
5. See Keen (2011) for a detailed general discussion. See Anger and Barker (2015) for a recent shorter discussion in the context of climate policy.
6. See the description of SFC models in Section 3. One other potential tool that has been developed is the Global Policy Model (see UN DESA, 2009), although it does not go into sectoral detail.
7. There is some contention regarding whether Keynes himself supported the theory of endogenous money, see Dow (1997) for a discussion.
8. Leverage effects are the act of using deposits to finance multiple loans simultaneously.
9. In practice, central banks increase the size of deposits (and liabilities) of commercial banks held at the central bank.
10. Note that innovation is understood to mean any re-allocation of inputs to production and use of methods that leads to increasing profit at the firm level.
11. e.g. 'Walras not Keynes is the patron saint of CGE models', Robinson and Devarajan (2012), p. 282.
12. It is, of course, possible to specify a source of financing instead of assuming that the investment is financed by borrowing. When assessing policies directly additional assumptions are usually added (see e.g. European Commission, 2013). For example, public expenditure on energy efficient equipment is usually assumed to be financed by higher tax rates (i.e. enforcing savings on workers). Investment in renewables by the power sector may be financed by charging higher electricity prices to consumers over the lifetime of the plants, but this still implies higher borrowing that is paid back over the plant's lifetime.
13. If learning-by-doing cost reductions and/or cross-sectoral learning spillovers produce a permanently lower operation cost for the electricity system and/or lower cost of living, Schumpeter's description of economic development is then fully realized.
14. In other words, it is not sufficient to just specify multi-interactions to illuminate observed phenomena. For ABMs, while the input and output data may be clear, the intermediate processes generally remain obscure, unless the model is kept extremely simple (as in Arthur et al., 1997).
15. There are two possible exceptions. If climate impacts were included in the modelling exercise (which is not standard practice) it could be possible to get positive results. Also, if the scenario in a CGE model includes the removal of economic distortions (again not standard practice at least for climate and energy policy) then a positive outcome is possible (e.g. Jaeger et al., 2011).

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